JOINING OF DISSIMILAR MATERIALS SS304 AND COPPER PLATE USING LASER WELDING

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ABSTRACT

Laser welding with high power density, high degree of automation and high production rate is extremely advantageous in industrial applications. Steel and its alloys are extensively used in automobile frame, construction (harbour, tunnels etc.), transport (anchor chain, train, and rails), house hold application, owing to its high tensile strength and corrosion resistance property. Nd:YAG laser welding process has successfully used for joining a dissimilar metal AISI 304L stainless steel and pure copper plates. The current research is based on experiments on laser welding of 2mm thick AISI 304L stainless steel and 2mm thick pure copper plate using the Nd:YAG laser machine. In this study, a statistical design of experiment (DOE) will used to optimize selected LBW parameters (laser power, welding speed and pulse duration). Taguchi approach is using to design the experimental layout. A statistical design of experiment (DOE) method taguchi approach with help of MINITAB software method will utilized to develop an effective model to optimize weld strength and weld geometry by incorporating process parameters such as welding speed, laser power and pulse duration. Tensile strength of joint is determined using a universal testing machine (UTM).

Keyword :- *Laser welding, SS304 And copper, Nd:YAG laser,Ultimate tensile strength,L9 Orthogonal array,ANOVA,*

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1. INTRODUCTION

Laser (light amplification by the stimulated emission of radiation) welding is perhaps the latest addition to the ever-growing family of welding processes and is widely used welding technique in Automotive, Aerospace, and Electronic and Heavy manufacturing industries to join a variety of metals and alloys because of its high speed, fine welding seam quality, low heat input per unit volume, deep penetration, and narrow heat affected zone, and reduced tendency to cracking. Lasers generate light energy that can be absorbed into materials and converted into heat energy. LBW is a high-energy-density welding process and well known for its deep penetration, high speed, small heat-affected zone, fine welding seam quality, low heat input per unit volume, and fiber optic beam delivery [01]. The energy input in laser welding is controlled by the combination of focused spot size, focused position, shielding gas, laser beam power and welding speed.

In the present scenario demand of the joining of dissimilar materials continuously increases due to their advantages, which can provide appropriate mechanical properties and good cost reduction. The weld itself is narrow and volume of intermetallics may be reduced to acceptable limits. It may be possible to offset the beam in one direction or the other allowing control over the composition of the resulting alloy. Also it is feasible to produce sound joints by these methods on a laboratory scale.

While in the process of joining, Solubility of copper and steels particulates remains undissolved constitutions with incomplete phase transformations due to the cooling rates involved with solidification. Simulation offers the insight understanding of the complex temperature state and stress distribution and around the joint location with proper selection of input parameters.

Taguchi method design was used to carry out the experimental design. ANOVA in Minitab software is used to establish the relationships between the laser welding input parameters i.e pulse duration, laser power and welding speed and the output responses i.e ultimate tensile strength. The result analysis of this project will be carried out by using Minitab Software.

2. LITRATURE REVIEW

T.A. Mai, A.C. Spowage (2004)[02] studied “the Characterisation of dissimilar joints in laser welding of steel–kovar, copper–steel and copper–aluminium” In this study, The Characterization of dissimilar joints in laser welding of steel–kovar, copper- steel and copper–aluminium using Nd:YAG laser welding. The input parameter for experimental range of this paper was Power (350W), Frequency (500 Hz), Pulse duration (-0.5 to 2.0 ms) and Velocity (150mm/s). The observation parameter are EDX, X-ray imaging. The results of this experiment shows that Melting ratio can play important role in defect free welding of dissimilar metal weld joint. So that heat distribution per unit area should be control and the formation of brittle intermetallic phases could be avoided.

K. Kalaiselvan, A. Elango, N. M. Nagarajan, (2014) [03] investigated Comparative Studies on Dissimilar Metals thin Sheets Using Laser Beam Welding In this paper author discuss about the effect of different parameters on lbw of SS/AL, CU/AL And TI/AL sheets. Laser Power, Welding Speed, Power Density, Beam Diameter, LBW Focal Distance, LBW Shielding Gas Flow. In this paper An overview of laser beam welding of dissimilar materials focusing on aluminum to other materials has been studied. Furthermore, this paper review showed that there is a significant progress in laser welding of dissimilar materials. Most of the cited research studies are focused on understanding the parameters of various welds. There were large differences in melting point between the sheets of Ti and Al welding. There was a region within the lower melting point sheet which had melted but not mixed with the main weld pool. Compare to SS/Al and Cu/Al, Ti/Al gives sound weldment in Aluminium rich region.

L. K. Pan, C. C. Wang, Y. C. Hsiao and K. C. Ho (2004) [04] studied Optimization of Nd:YAG laser welding onto magnesium alloy via Taguchi analysis,In this study, To achieve the maximum ultimate tensile strength by making the use of a Nd:YAG laser for thin plate magnesium alloy butt welding process parameter were optimized using the Taguchi analytical methodology . The factors can be the shielding gas, laser energy, convey speed of work piece, point at which the laser is focused, pulse frequency, and pulse shape. As the output of research, the optimal combination of welding parameters for laser welding is Ar as the shielding gas, a 360 W laser, a work piece speed of 25 mm/s, a laser focus distance of 0.0 mm, a pulse frequency of 160 Hz, and a type III pulse shape. The ultimate tension stress was maximum at an overlap of the 23 welding zone of approximately 75%. The optimal result was confirmed with a superior ultimate tension stress of 169 MPa, 2.5 times larger to that from original set for laser welding.

Vicente Afonso Ventrellaa, José Roberto Berretta, Wagner de Rossib (2007) [05] investigated pulsed Nd:YAG laser seam welding of AISI 316L stainless steel thin foils, Researcher investigated the Pulsed Nd: YAG laser welding of AISI 304 to AISI 420 stainless steels. They have studied the influence of the laser beam position, with respect to the joint, on weld characteristics. Specimens were welded with the laser beam incident on the joint and moved 0.1 and 0.2mm on either side of the joint. The joints were examined in an optical microscope for cracks, pores and to determine the weld geometry. The microstructure of the weld and the heat affected zones were observed in a scanning electron microscope. An energy dispersive spectrometer, coupled to the scanning electron microscope, was used to determine variations in (weight %) the main chemical elements across the fillet weld. Vickers micro hardness testing and tensile testing were carried out to determine the mechanical properties of the weld.

E.M. Anawa, A.G.Olabi(2007), [06] studied using Taguchi method to optimize welding pool of dissimilar laser-welded components In this study, selection of the materials was AISI 316 stainless-steel and AISI 1009 low carbon steel plates using for CO_2 laser welding. Selected input parameters of experimental range were Power (1.00-1.50KW), Welding speed (500-1000 mm/min) and Defocusing distance (-1 to 0 mm). The observation parameter for this study using software MINITAB 13, ANOVA and Design-expert 7.Investigation conclude that Increasing velocity the weld vaporization of metal decreases, With increasing power the weld width (W1) slight increase, With increasing power density the inside weld width (W2) also increases. Change the Defocusing distance (F) effects W1, W2 and did not affect the area. This may be interpreted that as F decreased, W1 increased, W2 decreased and vice versa, so the total area (A) will not be affected by changing F. Using laser welding could produce a small welding pool and a narrow HAZ.

K. Subbaiah, M. Geetha, B. Shanmugarajan And S. R. Koteswara Rao (2014) [07] studied Effect of focal position on CO_2 laser beam welded Al-Mg-Mn alloy, Author compared mechanical properties (yield strength and hardness) achieved from Laser welding with TIG on 5 mm thick aluminium alloy AA 5083-H321 using 3.5KW CO2 laser. Following conclusion were made i) the low heat input of laser beam welding effectively reduced the size of the fusion zone and heat affected zone compared to TIG. ii) 26% higher yield strength and 7.5% higher UTS was obtained respectively in LW compare to TIG. iii) Absolute minimum of the hardness profile is located in the fusion zone in the case of TIG welding and at the base metal in the case of Laser beam welding.

Vijay D. Bhujbal, Ashok P.Tadamalle (2013) [08] studied Optimization of Laser Welding Process by Fuzzy Logic Technique Optimization of laser welding process by fuzzy logic technique. In this work, Laser welding of two dissimilar metals namely Inconel 625 and stainless steel 304L plates has been carried out to attain optimum tensile strength of the weld joint. The process parameters such as laser power P (1200-1400 W), travel speed T (1-2 mm/sec), laser energy E (170-200 Joule/mm2), and laser current C (155-175 Ampere). They have used Taguchi method based on four factor three levels design. The optimization of the process parameters is carried out by using fuzzy logic technique and the results are compared by regression analysis and ANOVA. They concluded that Regression analysis that current and power are the most significantly affecting parameters. Estimated UTS values are within difference of 6 N/mm2 and 38 N/mm2 and Estimated DOP values are within difference of 4 microns for process parameters E, P, T for Inconel 625+SS and SS+SS specimens respectively. It was found that values of parameters namely depth of penetration and ultimate tensile strength obtained from fuzzy logic and regression was in close agreement with each other.

Rattana Borrisutthekul, Yukio Miyashita, Yoshiharu Mutoh (2005) [09] studied dissimilar material laser welding between magnesium alloy AZ31B and aluminum alloy A5052-O. Dissimilar material laser welding between magnesium alloy AZ31B and aluminum alloy A5052-O. Nd–YAG laser with continuous wave was used for welding. In that study, the normal center-line welding of lap joint was carried out by laser welding. It was found that the intermetallic layer formed near interface between two metals significantly degraded the joining strength. FEM heat transfer analysis was carried out to find out an available method to control penetration depth and width of molten metal, which contributes to control thickness of intermetallic compound layer. They have concluded that the shallow penetration depth into lower plate, thin intermetallic layer and then higher joining strength could be obtained in the edge-line welding lap joint.

Miroslav Sahul, Martin sahul, Milan Turna, Paulina Zackova (2015) [10] studied disk Laser Welding of Copper to Stainless Steel The paper concerns with welding of copper to stainless steel. Technically pure Cu and AISI 304 austenitic stainless steel with the thickness of 2.0 mm were suggested as experimental metals. Technically pure Cu and AISI 304 austenitic stainless steel with the thickness of 2.0 mm were suggested as experimental metals. TruDisk 8002 laser with the wavelength of 1.03 µm and a maximum power of 8.0 kW was used for production of dissimilar metal welds. Laser power from the range of 2.3 to 2.9 kW and welding speed from 35 to 50 mm/s were used for welding dissimilar metals. Focal position was direct on the surface of welded metals. Helium with flow rate of 17 l/min was used for shielding of molten weld metal. Light microscopy, EDX microanalysis and micro hardness measurements across copper - fusion zone - stainless steel interface were performed in order to study the properties of the weld joints. No cracking in the HAZ of austenitic stainless steel were observed. The weld metal exhibited heterogeneous character. Based on the analysis of cross sections of weld joints, it can be stated that the higher the welding speed, the smaller the weld joint width. The maximum weld with was attained in the case of application of welding speed of 30 mm/s (when laser power of 2.9 kW and focusing 0 mm was used). The minimum weld metal width was documented when welding with 50 mm/s welding speed (laser power of 2.9 kW and focusing 0 mm) was carried out. From the course of micro hardness arises, that the hardness of the fusion zone is greater than the hardness of weaker base material, i.e. copper. The concentration of copper decreases in the direction from copper sheet towards fusion zone. Contrary, the concentrations of Fe, Cr and Ni increase in the direction from fusion zone towards austenitic stainless steel side.

K. K. Kanaujia , M. P. Rout, B. C. Behera, S. K. Sahoo, B.K.Maharana (2011) [11] studied optimization of Tensile Strength of AISI304 Stainless Steel and Copper using Nd:YAG Laser Welding. Nd:YAG laser welding process was successfully useful for joining a dissimilar metal AISI 304 stainless-steel and copper plates. In this study, a statistical design of experiment (DOE) was used to optimize selected LBW parameters (laser power, welding speed and pulse duration). Taguchi approach was used for the selected factors. Joint strength was determined using the universal testing machine (UTM). The results were analyzed using analyses of variance (ANOVA) and the signal-to-noise (S/N) ratios for the optimal parameters, and then compared with the base material.

The following points can be determined from this study:

(i) Laser welding is a very effective process to join stainless steel and copper.
(ii) Laser power has strong effect on fusion area. By changing the P value the response will be changed noticeably, so the P value should be logically selected.
(iii) Welding speed has the stronger effect on the fusion area size among the selected parameters; which is inversely proportional to response.
(iv) Using laser welding could produce a small welding pool and a narrow HAZ.

3. MATERIALS AND METHODS

Material selection is the most important to this experiment because different materials have different working parameters based of their properties. The right selection of the welding material is the most important aspect to take into consideration in laser welding process. The materials used in this investigation are plates of AISI 304L stainless steel and pure copper in dimensions of 100mm gauge length 20mm width and 2mm of thickness, each have used as a work pieces materials. Good surface finish is required for the work piece for laser welding.

Table 1 Chemical composition of copper

Material	C	Si	Cu
Copper	3.88	0.82	95.29

Table 2 Chemical composition of AISI 304 stainless steel

Material	C	Si	Cr	Mn	Fe	Ni	Tb
AISI 304 stainless steel	3.28	3.34	14.89	1.07	53.54	5.2	18.61

Prior to joining materials should be cleaned thoroughly. If the component contains residual from prior processing, they are often baked to remove moisture and contaminants. Surface are abutting edges should be as smooth as possible to avoid welding imperfections the mechanical properties of base materials should be measured to establish a baseline against which the properties of the welded joint can be compared.

Company Profile

From past reviews and contents collected, required experimental work designed at the Scantech laser pvt. ltd. A-517,TTC industrial area,MIDC, Mahape, Navi Mumbai-400710.
Scantech is worldwide known for its technical innovations in all the fields of custom laser applications. Scantech Laser was founded in the year 1991 and since then, history of the company shows that pioneering ideas and continuous R&D work have been the keys to the success of the company. Laser machines manufactured by Scantech are of international quality & safety standards are well considered in manufacturing of machines.

Technical Specification of Laser Welding Machine

Parameter	Range
Laser type	Nd:YAG
Max. mean power	400 W
Pulse peak power	9 kW
Max. pulse energy	35J
Pulse duration	03-20 ms
Pulse frequency	16-50 hz
Focus diameter	0.2-2.0 mm
Wavelength	1064 nm

Table 3 Specification of laser welding machine

Parameters considered for experiment

Input Parameters

1) Pulse Duration

2) Laser Power

3) Welding Speed

Output Parameter

1) Ultimate Tensile Strength

2) Macrostructure Examination

Factors	Level 1	Level 2	Level 3
Laser Power (watt)	150	200	250
Welding Speed (mm/min)	3.2	3.5	3.8
Pulse Duration (ms)	3	4	5

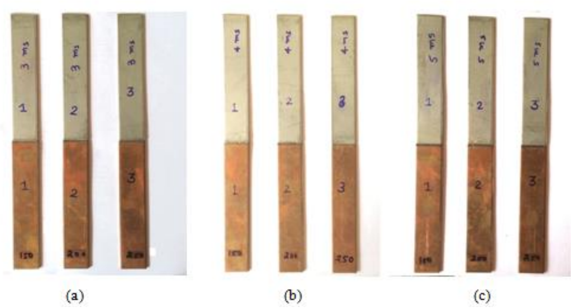
Table 4 Factors with level value

4. Experimental Work

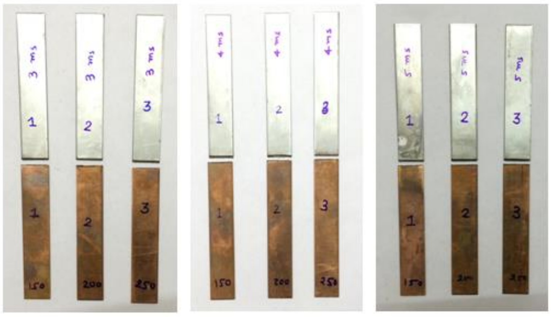
No.	Input Parameter			Output Parameter	
	Pulse Duration (m.s)	Laser Power (watt)	Welding Speed (mm/sec.)	UTS (N/mm^2)	Load (N)
1	3	150	3.5	5.482	169
2	3	200	3.2	24.909	758
3	3	250	3.8	47.284	1387
4	4	150	3.2	23.200	706
5	4	200	3.8	70.423	2195
6	4	250	3.5	99.417	3108
7	5	150	3.8	18.358	566
8	5	200	3.5	29.561	884
9	5	250	3.2	29.866	926

Table 5 Experimental details with input and output parameter

Specimen For laser welding



Specimen before Tensile test

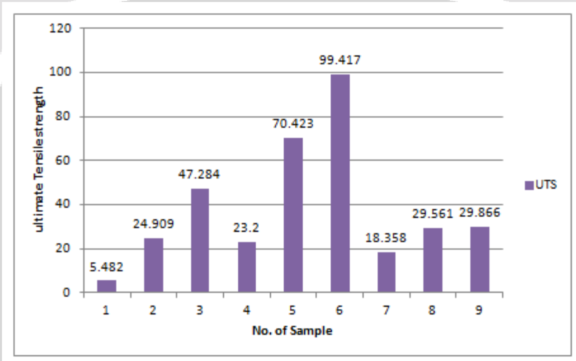


(a) (b) (c)

Specimen after Tensile test

5. RESULT AND DISCUSSION

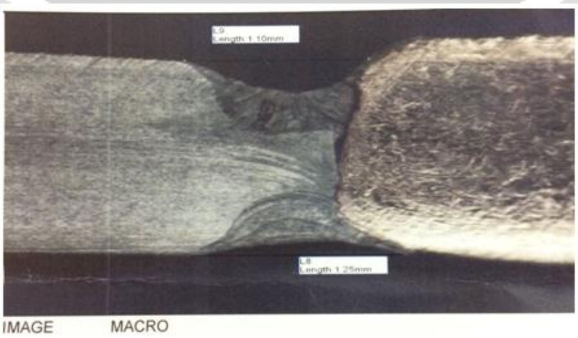
[A] Experimental Result for ultimate tensile strength vs. no. of sample used for laser welding.



From the table experimental details with input and output parameter gives various value of ultimate tensile strength which is shown in the figure above. From the result table determine the maximum value of tensile strength 99.417 N/mm^2 and load 3108 N for sample no.3 (pulse duration 4 ms) with laser power 250 watt and the welding is 3.5 mm/sec.

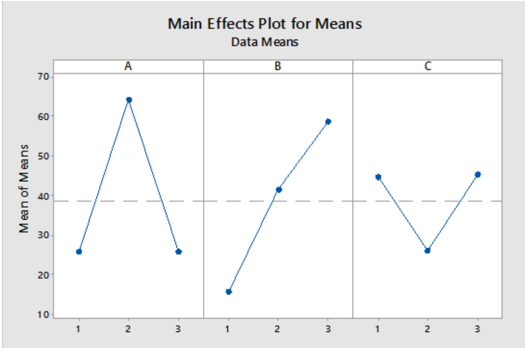
[B] Macrostructure Examination

Result from this test shows that macrostructure had a lack of fusion and weld width 1.10mm and 1.25mm at upper and lower side.

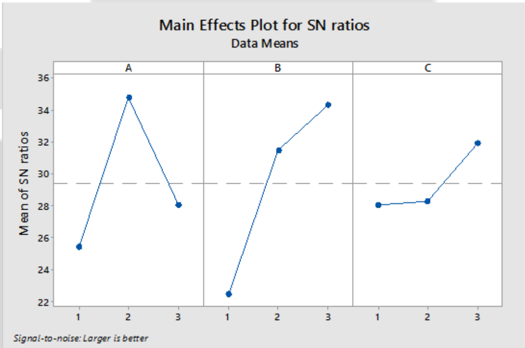


Macrostructure Examination

[C] Analysis of Results and Discussions



Response table for Means



Response table for S/N Ratio

[D]Analysis of Variance (ANOVA) For UTS

Sources	**Degree of freedom f**	**Sum of squares S**	**Variance (Mean square)**	**Variance ratio F**	**Percentage contribution P**
Factor A	2	2954.79	1477.40	8.246	42.97
Factor B	2	2834.29	1417.15	7.9091	41.22
Factor C	2	728.38	364.19	2.0326	10.59
Error (e)	2	358.36	179.18	1	5.21
Total	8				

Table 6: The ANOVA Results For UTS

Conclusions:

The effects of Pulse Duration, Laser Power and Welding speed on quality characteristics of laser welding of stainless steel 304 and copper plates specimens have been studied in this work. The L9 orthogonal has been used to assign the identified parameters. ANOVA analysis was performed for the analysis purpose which shows that most significant parameters that influenced the tensile strength of the weld. As per ANOVA Analysis we can found that the Factor A –Pulse duration and Laser Power is most significant factor for ultimate tensile strength for laser welding of SS 304 and copper plates.

There were large differences in melting point between the sheets of SS304 and Cu welding. The results of this experiment shows that Melting ratio can play important role in defect free welding of dissimilar metal weld joint. So that heat distribution per unit area should be control and the formation of brittle intermetallic phases could be avoided. There is difference between melting ratio of two material because of thermal conductivity of copper is higher so for the sound weld joint SS304 should be pre-heated. Thus defect free weld joint will be determined.

References

[1]. Steen W.M.,Laser material processing‖, Springer, London, 1991.
[2]. T.A. Mai, and A.C. Spowage, "Characterisation of dissimilar joints in laser welding of steel–kovar, copper–steel and copper–aluminium", Materials Science and Engineering A 374, 224–233 (2004)
[3]. K. Kalaiselvan, A. Elango, N. M. Nagarajan, Comparative Studies on Dissimilar Metals thin Sheets Using Laser Beam Welding - A Review, World Academy of Science, Engineering and Technology International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering Vol:8, No:10, 2014 1728 International Scholarly and Scientific Research & Innovation 8(10)(2014)
[4]. L. K. Pan, C. C. Wang, Y. C. Hsiao and K. C. Ho, Optimization of Nd:YAG laser welding onto magnesium alloy via Taguchi analysis, www.elsevier.com/locate/optlastec (2004)
[5].Vicente Afonso Ventrellaa, José Roberto Berretta, Wagner de Rossib,Pulsed Nd:YAG laser seam welding of AISI 316L stainless steel thin foils, Journal of Materials Processing Technology (2007)
[6] E.M. Anawa, and A.G.Olabi, "Using Taguchi method to optimize welding pool of dissimilar laser-welded components," Optics & Laser Technology 40, 379–388 (2008)
[7] K. Subbaiah, M. Geetha, B. Shanmugarajan And S. R. Koteswara Rao , Effect of focal position on CO_2 laser beam welded Al-Mg-Mn alloy, ijaer (2014)
[8]. Vijay D. Bhujbal, Ashok P.Tadamalle, Optimization of Laser Welding Process by Fuzzy Logic Technique, (IJESIT), Volume 2, Issue 4 (July 2013)
[9]. Rattana Borrisutthekul , Yukio Miyashita, Yoshiharu Mutoh, Dissimilar material laser welding between magnesium alloy AZ31B and aluminum alloy A5052-O,Science and Technology of Advanced Materials (2005)
[10]. Miroslav Sahul, Martin sahul, Milan Turna, Paulina Zackova, Disk Laser Welding of Copper to Stainless Steel, Advanced Materials Research Vol. 1077 (2015)
[11]. K. K. Kanaujia , M. P. Rout, B. C. Behera, S. K. Sahoo, B.K.Maharana, Optimization of Tensile Strength of AISI304 Stainless Steel and Copper using Nd:YAG Laser Welding, www.researchgate.net/publication/270648395 (June 2011)